CHAPTER 6
HAZARDOUS WASTE FACILITY DESIGN ELEMENTS

6-1. Introduction

a. Federal regulations on hazardous waste land treatment, storage and disposal facilities (40 CFR 264) are expressed as performance standards; therefore, while required design elements are stipulated, design details are not. The EPA, however, as the agency charged with enforcement of the regulations and permitting of hazardous waste facilities, has provided specifications for the required design elements in a series of RCRA guidance documents. These documents, referenced in appendix A, contain recommendations for constructing the design features that the agency considers the minimum necessary to achieve the required performance standards. This chapter focuses on the key elements required by the regulations, including flood control systems (para 6-2), liner systems (para 6-3), leak detection and leachate collection and removal systems (para 6-4), surface water control systems (para 6-5), gas control systems (para 6-6), final cover (para 6-7), and special design features (i.e., dikes and overtopping controls and wind dispersal methods) (para 6-8). EPA specifications are generally adhered to; however, variations in design are suggested if the proposed alternative meets the performance standards set in paragraph 264, Note, however, that in cases where DA criteria are more stringent than state or federal regulations, Army standards are preeminent. Table 5-1 in chapter 5 summarizes the design elements required for each type of DA hazardous waste facility.

b. The limited scope of this design manual prevents detailed treatment of all elements of design. Reference to pertinent resource documents, noted in the text, will be necessary to provide the needed design detail.

c. Facility operations, which are treated generally in chapters 5 and 7, are discussed in this chapter only if the operational element is integrally connected with facility design and a necessary component of achieving performance standards.

6-2. Flood control systems

a. To minimize the adverse impact that washout of hazardous wastes could have on the environment, land disposal facilities must be located and designed to prevent flooding by a 100-year return frequency flood (or any greater return specified by state regulations).

(1) RCRA regulations (40 CFR 264.18(b)) require that washout be prevented, unless the owner or operator demonstrates that wastes can be removed before flooding, and that no adverse effect would result if washout were to occur. While removal of wastes is an acceptable option, it should be avoided in favor of installing flood control features. At existing sites, an evaluation should be made of potential flood levels and the ability of design features to prevent flooding. If such features are not feasible, procedures should be developed for removal of wastes before flooding or for preventing the adverse effects of washout.

(2) Evaluation and assessment of the 100-year flood level for land disposal facilities should be based on analyses performed by the local Corps of Engineers District Office or other federal or local flood agencies, and/or on data collected at any upstream control facilities. Should such information be lacking, the need for determining the probable flood level by other means should be assessed.

(3) Earthen embankments (levees) constructed of compacted impervious soil, are commonly used to form barriers to flood waters and protect the facilities behind them. Levees may be constructed along the perimeter of disposal sites or at the base of fill along slope faces subject to inundation. To provide sufficient flood protection, levee elevations should be at least 2 feet above the 100-year flood level.

(4) Figure 6-1 presents design features of a typical levee at the perimeter of a new or uncompleted landfill. If lack of soil or available space limit levee construction, landfill slopes subject to flooding can be protected by a heavy clay structure such as that also shown in figure 6-1.

b. Additional features which may be needed for flood control structures include subsurface cutoff trenches and interior drainage structures to control seepage or run off. Furthermore, although levees are designed for long-term flood protection, proper functioning can only be ensured by periodic inspection and maintenance to guard against bank caving or sloughing, erosion and settlement of the foundation.

6-3. Liner systems

a. Introduction. Liner systems are required for all hazardous waste landfills, surface impoundments and waste piles. Liners required as part of the final cover at facility closure are discussed in paragraph 6-8. This section refers to required base liner systems. Double liners with a leak detection system are required at all DA installations unless waivers are obtained from USACE (DAEN-ECE-G), Washington, DC 20314.

(1) Specific federal regulations concerning base liner systems are summarized in table 6-1. The liner system must function for the active life of the waste unit through scheduled closure and be capable not only

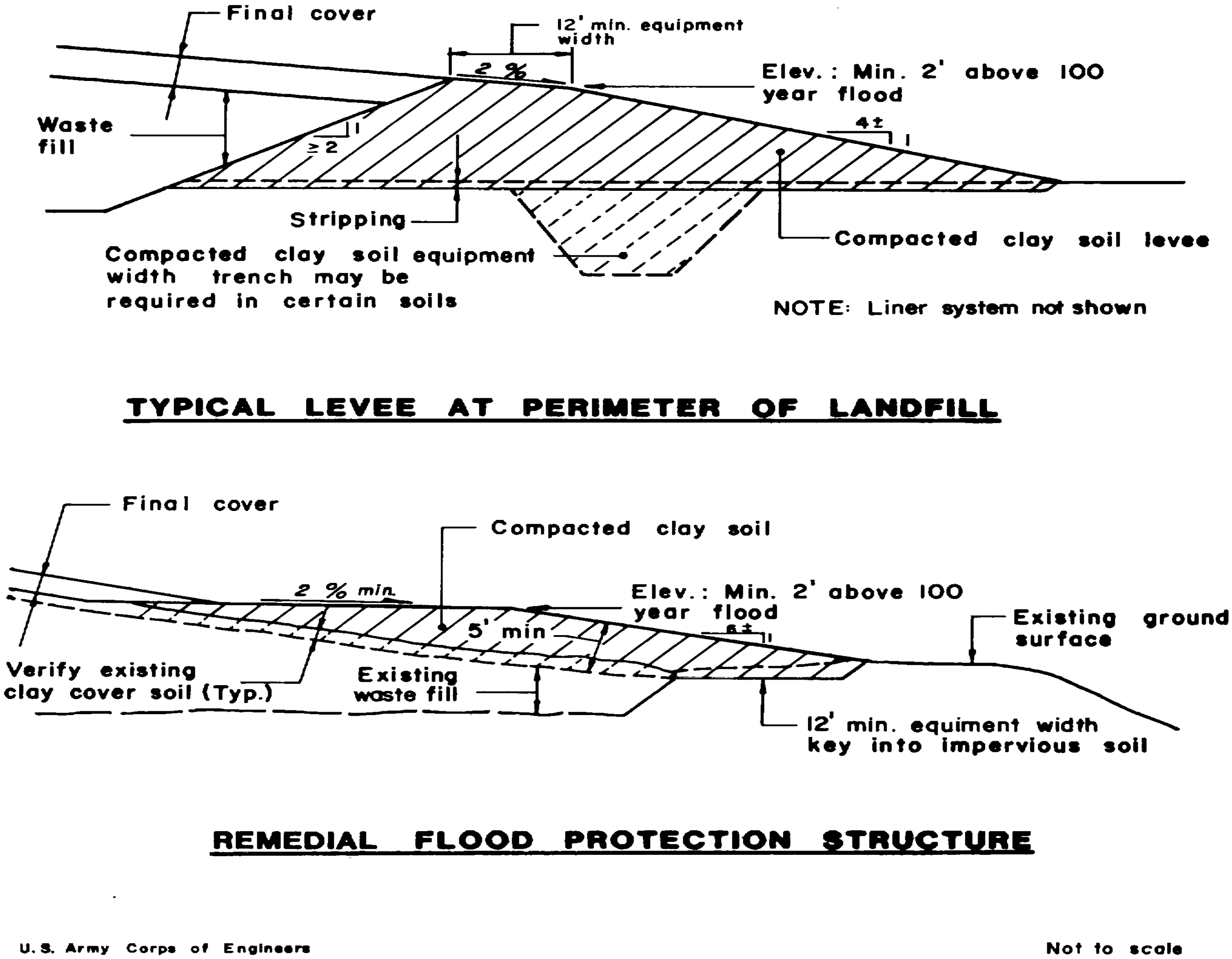


Figure 6-1. Flood control structures.

of preventing migration of liquids from the facility, but also allowing no infiltration of liquids into the liner itself. The latter requirement in effect mandates use of a synthetic material as a primary liner at most hazardous waste units.

(2) Leachate collection and removal systems, capable of maintaining a leachate head no greater than 1 foot, must be installed in a drainage layer above the liners in all landfills and waste piles; leak detection systems are also required. Specific design provisions for leachate collection and leak detection systems are discussed in paragraph 6-4.

(3) The EPA has developed design recommendations for various elements of the required liner system. Although the EPA currently considers its recommendations the minimum acceptable to ensure achievement of the performance goals set forth in the regulations, variations in system design are permitted upon successful demonstration of comparable performance.

b. Elements of the liner system. Liner systems for

Table 6-1. Requirements for Liner Systems

Design Requirements	Section of 40 CFR 264 Describing Requirements K Surface Impoundments	L Waste Pile	M Land Treatment	N Landfill
Except for an existing portion, a unit must have a liner that is designed, constructed, and installed to prevent any migration of wastes out of the unit to the adjacent subsurface soil or ground water or surface water at any time during the active life (including the closure period).	264.221(a)	264.251(a)(1)	NA	264.301(a)(1)’
Constructed of materials that have appropriate chemical properties and sufficient strength and thickness to prevent failure due to pressure gradients (including static head and external hydrogeologic forces), physical contact with the waste or leachate to which they are exposed, climatic conditions, the stress of installation, and the stress of daily operation. Installed to cover all surrounding earth likely to be in contact with the waste or leachate.	264.221(a)	264.251(a)(1)	NA	264.301(a)(1)
Placed upon a foundation or base capable of providing support to the liner and resistance to pressure gradients above and below the liner to prevent failure of the liner due to settlement, compression, or uplift.	264.221(a)	264.251(a)(1)	NA	264.301(a)(1)
	264.221(a)	264.251(a)(1)	NA	264.301(a)(1)
Liner systems must be monitored and inspected during construction and installation, (except in the case of existing portions of units exempted from liners, as noted above).	264.226(a)	264.254(a)	NA	264.303(a)
Cover systems (e.g., membranes, sheets, or coatings) must be inspected for uniformity, damage, and imperfections (e.g., holes, cracks, thin spots, or foreign materials) Immediately after construction or installation	264.226(a)	264.254(a)	NA	264.303(a)
Soil-based and admixed liners and covers must be inspected for imperfections including lenses, cracks, channels, root holes, or other structural non-infirmities that may cause an increase in the permeability of the liner or cover	264.226(a)	264.254(a)	NA	264.303(a)
Adapted from 40 CFR 264				

• For landfills, (and surface impoundments and waste piles operated for more than 30 years), regulations include an additional requirement that wastes not migrate into the liner during the active life of the site.

all facilities must be (1) constructed in unsaturated soil above the seasonal high water table, (2) placed on a foundation which will provide adequate support to the liner, and (3) installed to cover all earth likely to come into contact with waste or leachate. Required elements of the liner system depend on the type of facility and the anticipated period of time from first placement of waste to site closure.

(1) Surface impoundment liner systems depend on whether the impoundment is permitted for storage (requiring removal of all wastes, waste residues and liners at closure) or for disposal (requiring removal of free liquids, stabilization of wastes and capping at closure). The following elements are required for DA impoundments:

- Primary synthetic liner
- Secondary (clay soil or synthetic) liner
- Leak detection system
- Monitoring wells

(2) Waste piles, which can be permitted only as storage facilities, require base liner systems consisting of a single liner of soil (clay), synthetic material, or ad- mixed material, and a leachate collection and removal system. If closure is not scheduled for 10 years or more, a synthetic liner is to be used, and the base liner system should consist of-

- Leachate collection and removal system above primary liner
- Primary liner of synthetic material
- Secondary liner of clay soil or synthetic material
- Leak detection system between liners

(a) Alternatively, admixed materials such as concrete and asphalt may be used for long-term storage if physical and chemical analyses of their characteristics indicate they will not deteriorate during the life of the waste pile. Admixed liners are preferred for waste piles where repeated removal and replacement of wastes may occur, since synthetic membrane liners could be easily damaged by the required waste-handling equipment, and exposed areas of clay liners could dry out and crack. Reinforced concrete with appropriate coatings would be a suitable liner in such cases.

(b) Waste piles storing only dry wastes which will not generate leachate through decomposition or reaction are exempt from the provisions of this technical manual, provided they are located inside or under structures protected from infiltration of moisture.

(3) Landfill base liner systems should consist, at a minimum, of-

- Leachate collection and removal system
- Primary liner of synthetic material
- Secondary liner of clay soil or synthetic material
- Leak detection system between liners
- Monitoring wells

(4) The types of liner systems recommended for landfills, surface impoundments and waste piles are depicted in figures 6-2 and 6-3. Specific design elements necessary to ensure the performance of DA hazardous waste facilities include the following:

(a) Synthetic liners should be a minimum 30 mil in thickness when not reinforced, but a minimum 36 mil if reinforced. They must be carefully selected for compatibility with the waste and leachate to be contained.

(b) Soil liners for DA facilities should be constructed of a minimum 3-foot compacted layer of soil materials with a permeability of 1 x 10-7 cm/sec or less by EPA test methods.

(c) Soil liners should be tested for compatibility with the hazardous waste designated for disposal. A list of compatible wastes should be made available to the facility operator and made part of the permanent record. This list should also be included in facility operation manuals and related documents.

(d) Drainage layers constructed above the liners as part of leachate control or leak detection should be at least 12 inches thick, have a minimum hydraulic conductivity of 1 x 10-3 cm/sec, and be sloped at >, 2 percent. Sands should be classified as either SW or SP by the USCS, with less than 5 percent passing the No. 100 sieve. In addition, sands intended to act as filters must meet filter graduation requirements, such as those shown in chapter 5 of TM 5-820-2.

c. Liner system exemptions. Retrofitting of liners is not required in already existing portions of hazardous waste units, but liners are normally required for all new portions of existing facilities, unless the owner/operator demonstrates to the EPA and USACE (DAEN-ECE-G), Washington, DC 20314, that no hazardous constituents will migrate from the facility to ground or surface waters. Migration of liquids into or out of the space between the liners is prevented by lapping and sealing the liner edges at the surface.

d. Liner types. A variety of liner materials are available for control of hazardous wastes. Table 6-2 presents their principal characteristics, advantages and disadvantages. While soil liners are suitable for use as secondary liners and, in certain applications, as the only liner, synthetic membrane liners are considered by the EPA to be the primary mechanism for long term containment of waste and leachate from hazardous waste land treatment and disposal facilities. However, to ensure the continued effectiveness of the liners, whether soil or synthetic material, they must be compatible with the waste and leachate they are to contain and be properly installed.

e. Liner characteristics. The major categories of liners are soil liners and synthetic liners; their characteristics are summarized in table 6-2 and described in greater detail below.

(1) Soil liners may be constructed of native clay materials exhibiting a remolded permeability of 1 x 10-7 cm/sec or less and obtained on site, from selected borrow areas, or from off-site sources. The soil liner should generally fall into the CL/CH Unified Soil Classification System (USCS) with not less than 50 percent by weight passing a No. 200 sieve (US Standard), a liquid limit between 35 and 60, and a plasticity index above the "A" Line in the plasticity chart of the USCS. If available soils do not have the required low permeability, they can be blended with clay, bentonite or other additives.

(a) Soil liners have been the liner of choice at many solid waste disposal facilities (when available on site) because of their natural attenuation of many chemical substances, resistance to leachate, high caution exchange capacity, and relatively low cost. In all cases, on-site clays must be prepared for use as liners in accordance with paragraph 6-3g(1). However, because they do permit migration of leachate into the liner, the EPA considers soil liners unacceptable as the primary line of defense in preventing hazardous waste migration. Except for surface impoundments permitted for storage only and for waste piles, synthetic liners are specified for the primary liner. Soil liners are acceptable as secondary liners.

(2) Synthetic liners currently in use at hazardous waste land facilities include the following types:

- Polyvinyl chloride (PVC)
- Chlorinated polyethylene (CPE)
- High-density polyethylene (HDPE)
- Chlorosulfonated polyethylene, Hypalon (CSPE)
- Butyl rubber
- Epichlorohydrin rubber (ECO)
- Ethylene propylene terpolymer (EPT)
- Ethylene propylene rubber
- Neoprene (chloroprene rubber)
- Thermoplastic elastomers

(a) Flexible membrane linings, commonly called "plastics", include those with either polyvinyl chloride (PVC) or polyethylene (PE) bases. To produce the de-

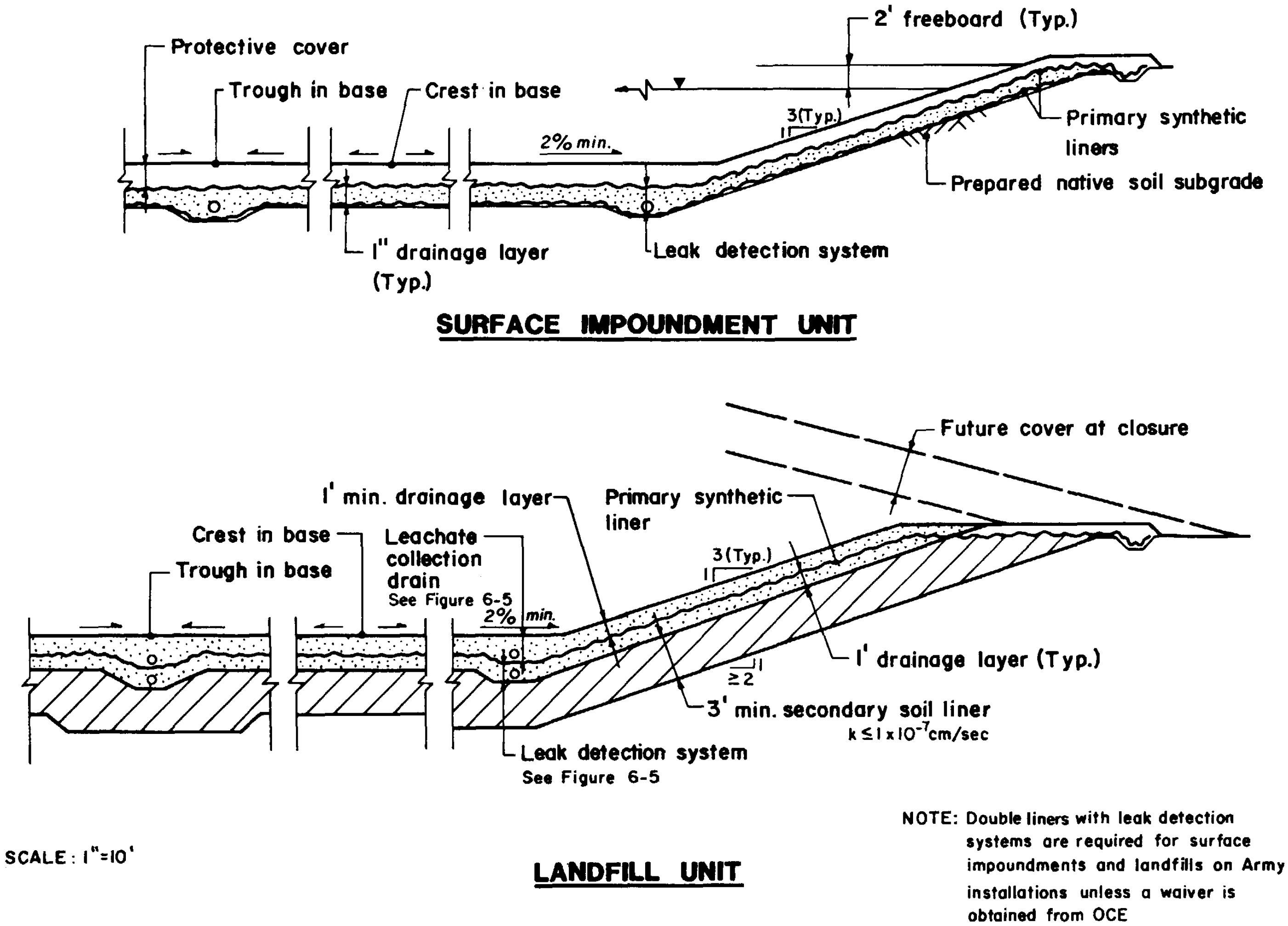


Figure 6-2. Base liner details for landfills and surface impoundments.

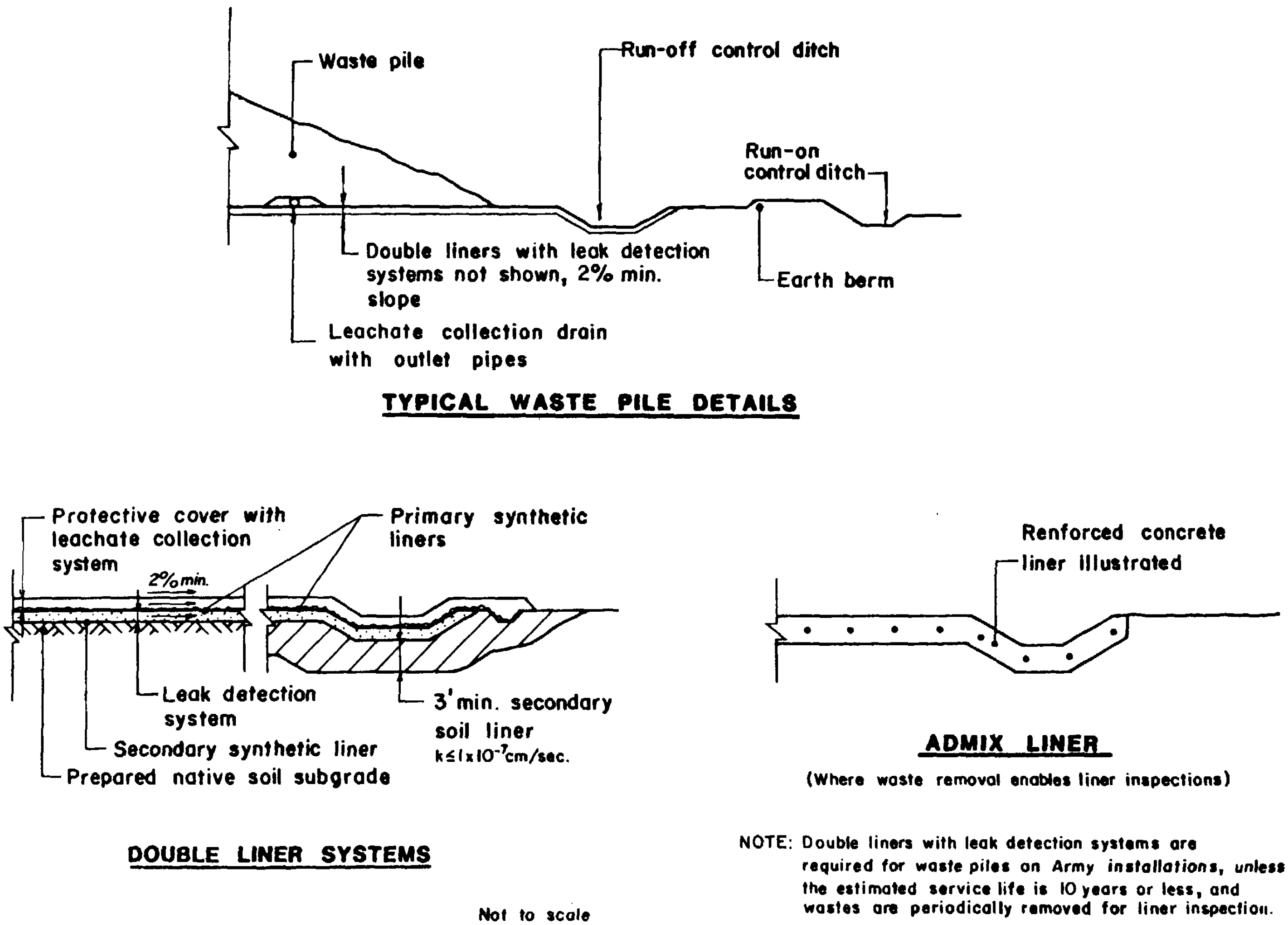


Figure 6-3. Base liner details for waste piles.

Table 6-2. Summary of Liner Types

Liner material	Characteristics	Range of costs a	Advantages	Disadvantages
Soils:				
Compacted clay soils	Compacted mixture of onsite soils to a permeability of 10^{-7} cm/sec	L	High cation exchange capacity; resistant to many types of leachate	Organic or inorganic acids or bases may solubilize portions of clay structure
Soil-bentonite	Compacted mixture of onsite soil, water and bentonite	L	High cation exchange capacity; resistant to many types of leachate	Organic or inorganic acids or bases may solubilize portions of clay structure
Admixes:				
Asphalt-concrete	Mixtures of asphalt cement and high quality mineral aggregate	M	Resistant to water and effects of weather extremes; stable on side slopes; resistant to acids, bases, and inorganic salts	Not resistant to organic solvents; partially or wholly soluble in hydrocarbons; does not have good resistance to inorganic chemicals; high gas permeability
Asphalt-membrane	Core layer of blown asphalt blended with mineral fillers and reinforcing fibers	M	Flexible enough to conform to irregularities in subgrade; resistant to acids, bases, and inor-	Ages rapidly in hot climates; not resistant to organic solvents, particularly hydrocarbons
Soil asphalt	Compacted mixture of asphalt, water, and selected in-place soils	L	Resistant to acids, bases, and salts	Not resistant to organic solvents, particularly hydrocarbons
Soil cement	Compacted mixture of Portland cement, water, and selected in-place soils	L	Good weathering in wet-dry/freeze-thaw cycles; can resist moderate amount of alkali, rganics and inorganic salts	Degraded by highly acidic environments
Polymeric membranes:				
Butyl rubber	Copolymer of isobutylene with small amounts of isoprene	M	Low gas and water vapor permeability; thermal stability; only slightly affected by oxygenated solvents and other polar liquids	Highly swollen by hydrocarbon solvents and petroleum oils; difficult to seam and repair
Chlorinated polyethylene	Produced by chemical reaction between chlorine and high density polyethylene	M	Good tensile strength and elongation strength; resistant to many inorganics	Will swell in presence of aromatic hydrocarbons and oils
Chlorosulfonate polyethylene	Family of polmers prepared by reacting polyethylene with chlorine and sulfur dioxide	H	Good resistance to ozone, heat, acids, and alkalis	Tends to harden on aging; low tensile strength; tendency to shrink from exposure to sunlight; poor resistance to oil
Elasticized polyolefins	Blend of rubbery and crystalline polyolefins	L	Low density; highly resistant to weathering, alkalis, and acids	Difficulties with low temperatures and oils
Epichlorohydrin rubbers	Saturated high molecular weight, aliphatic polethers with chloromethyl side chains	M	Good tensile and test strength; thermal stability; low rate of gas and vapor permeability; re sistant to ozone and weathering; resistant to hydrocarbons, solvents, fuels, and oils	None reported
Ethylene propylene rubber	Family of terpolymers of ethylene, propylene, and non conjugated hydrocarbon	M	Resistant to dilute concentrations of acids, alkalis, silicates, phosphates and brine; tolerates extreme temperatures; flexible at low temperatures; excellent resistance to weather and ultraviolet exposure	Not recommended for petroleum solvents or halogenated solvents
Neoprene	Synthetic rubber based on chloroprene	H	Resistant to oils, weathering, ozone and ultraviolet radiation; resistant to puncture, abrasion, and mechanical damage	None reported
Polyethylene	Thermoplastic polymer based on ethylene	L	Superior resistance to oils, solvents, and permeation by water vapor and gases	Not recommended for exposure to weathering and ultraviolet light conditions

See footnote at end of table.

Table 6-2-Summary of Liner Types-Continued

Liner material	Characteristics	Range of costs [a]	Advantages	Disadvantages
Polyvinyl chloride	Produced in roll form in various widths and thickness; polymerization of vinyl chloridemonomer	L	Good resistance to inorganic; good tensile, elongation, puncture, and abrasion resistant properties; wide ranges of physical properties	Attacked by many organics, including hydrocarbons, solvents - and oils; not recommended for exposure to weathering and ultraviolet light conditions -
Thermoplastic elastomers	Relatively new class of polymeric materials ranging from highly polar to nonpolar	M	Excellent oil, fuel, and water resistance with high tensile strength and excellent resistance to weathering and ozone	None reported
Portland cement	Hydraulic cement of silica, lime, and alumina	H	Excellent base for waste handling equipment	Cracking

a L-$1 to $4 installed costs per sq yd in 1981 dollars; M-$4 to $8 per sq. yd.; H-$8 to $12 per sq. yd.

Adapted from Technologies and Management Strategies for Hazardous Waste Control, Office of Technology Assessment, Congress of the U.S1983.

sired membrane, both material resins are mixed with monomers under controlled temperature and pressure conditions in a polymerizer. Many manufacturing companies utilize these basic resins in combination with their own compounding to produce specialty membranes. A list of the producers and suppliers of raw material polymer can be found in the EPA SW-870.

(b) Specifications for individual sheet materials can be obtained from the producer. Suppliers are also able to provide specifications for the base polymers and their individual synthetic membrane sheet.

(c) To increase tensile strength, to provide resistance to shrinkage, punctures and tears and to permit easier handling and seaming, a fabric reinforcement (scrim) may be laminated between two synthetic membrane sheets. When installing reinforced liners, care must be taken to ensure that all exposed edges are sealed. Failure to do so could result in the scrim acting like a wick and drawing in moisture, resulting in eventual liner breakdown.

f. Compatibility and physical testing. Since the prime purpose of a liner is to prevent liquids from leaving a hazardous waste facility, the physical integrity and chemical compatibility of the liner with the waste constituents must be ensured.

(1) *Soil liners*. Permeability tests, in which soil liners are brought into contact first with water, then with leachate or chemical waste, are the most important indicators of the compatibility of soil liner materials with the waste they are to contain. Permeability is a function of many variables, including pore size, pore space tortuosity, particle shape and size, and mineralogy of the soil material, the permeant characteristics, and temperature. The permeability of a soil liner can be affected by waste types that are incompatible with the liner material. For example, clay soils may exhibit high permeability when exposed to concentrated organics, especially organics of high and low pH.

(a) To test the permeability of soil materials, samples which have been tested for their physical, chemical and mineralogical properties may be remolded to specified moisture content and maximum dry density specified by ASTM D1557 to determine the permeability of test specimens. Test methods acceptable to EPA are contained in appendix A of the draft RCRA guidance documents for waste piles and surface impoundments. Both water and representative chemical wastes would be used for the permeant.

(b) Figure 6-4 shows the moisture content versus dry density curve for a clay liner, as well as the relationship between moisture content, relative compaction and permeability for a clay liner subjected to water and aqueous hazardous waste. All clay liners must have a permeability of 10-7 cm/sec or less.

(2) *Synthetic Liners*. Proof of the chemical resistance of the selected synthetic membrane liner is required by RCRA regulations. In recent years, all manufacturers of synthetic liners, as well as most suppliers, have operated testing facilities and developed chemical resistance tables and guides for their respective products. Reference to chemical resistance guideline sheets or compatibility charts that classify a generic flexible membrane liner will not, however, provide sufficient data on which to base a final liner selection, since the manufacturer's compounding can produce significant differences in liner properties and performance in the field. Furthermore, since the chemical characteristics of both liners and wastes are extremely variable, it is difficult to generalize concerning incompatibility. Data currently available, however, suggest that the following combinations of wastes and liner materials can be incompatible:

* Polyvinyl chloride (PVC) tends to be dissolved by chlorinated solvents.
* Chlorosulfonated polyethylene can be dissolved by aromatic hydrocarbons.
* Asphaltic materials may dissolve in oily wastes.
* Concrete- and lime-based materials are dissolved by acids.

(a) A test method accepted by the EPA for evaluating waste/liner compatibility involves exposing a liner sample to the waste or leachate encountered at the facility. After exposure, the liner sample is tested for strength (tensile, tear, and puncture) and weight loss. Any significant deterioration in the measured properties is considered evidence of incompatibility, unless it can be demonstrated that the deterioration exhibited will not impair the integrity of the liner over the life of the facility.

(b) Standard specifications for flexible membrane liners are currently being developed by the National Sanitation Foundation (NSF). Upon their final adoption, these standards will be used by the EPA to provide minimum recommendations on physical properties, construction practices and seaming. In the interim, the design engineer may review suggested standards in appendix IX of EPA SW-870.

g. Liner installation. Whether the liner to be installed is soil or synthetic material, a thorough analysis of the proposed liner foundation is necessary to ensure adequate support of the liner and resistance to pressure gradients above or below the liner. An unsuitable foundation could result in settlement, compression, or uplift of the liner which could lead to liner damage. An analysis of foundation suitability may include evaluation of geologic, hydrologic, geotechnical and other pertinent data. Such data are particularly important in the design of surface impoundments. Specific requirements for installation of soil liners and flexible membranes are discussed below.

(1) Proper installation of a soil liner is needed to maintain the specified permeability of 1 x 10-7 cm/sec or less. Prior to placement of the clay liner, the subbase must be properly prepared to ensure structural integrity and proper bonding with the clay liner. To ensure adequate compaction, soil materials should be spread in loose lifts no more than 6 inches thick, be wetted or dried to the specified moisture content of optimum or above, and be compacted with a sheepsfoot-type roller to the specified relative compaction. Specified values must be based upon the tested relationships between moisture content, relative compaction and permeability. See figure 6-4.

(a) Successive lifts should be placed and compacted until a liner thickness of 3 feet is achieved. The finished surface of the soil liner should then be rolled or bladed smooth. Installation of a clay liner should not be attempted under adverse weather conditions, such as heavy precipitation or freezing temperatures.

(b) Following installation, the liner should be inspected for imperfections, such as lenses, cracks, or other structural defects which could cause an increase in liner permeability. Until placement of waste or, in the case of a double-lined facility, the overlying synthetic liner, care must be taken to ensure that the liner does not dry out. Controlled moisture application or coating the liner with an asphaltic emulsion may be required in some instances to prevent drying and cracking. Protection from freezing is also an important consideration in colder climates.

(2) Considerations in installation of a synthetic membrane liner include providing protective soil layers above and below the liner and proper seaming of the liner. Failure to consider these important factors could result in liner failure and undermine the goal of complete waste containment. To ensure proper membrane liner placement, seaming, and placement of protective soil cover, the best installation procedures and practices should be developed for the type of membrane proposed. Guidance in installing synthetic liners should be obtained from experienced manufacturers of the membrane, fabricators who have assisted in preparing panel installation plans and have fabricated large panels of the materials, and experienced contractors. Project specifications for the installation of the liner should state the experience required for the manufacturer, the fabricator and the installing contractor for the project.

(a) Protection of the liner involves proper preparation of the subgrade and placement of protective soil layers. Procedures to be used in preparation of the surface include compaction, scraping and rolling to provide a smooth surface for the liner. A minimum 6inch layer of material not coarser than sand (classified by USCS as SP or SW, with less than 5 percent passing the No. 100 sieve) is recommended by the EPA as a protection against puncture, equipment damage, and exposure to the elements; sands which act as filters must meet filter graduation requirements, such as those shown in chapter 5 of TM 5-820-2. Note, however, that the EPA draft guidance document for liners permits substitution of drainage layers, on-site soils or soil liners for the 6-inch sand layer.

(b) In surface impoundments, the liquid material overlying the liner is considered sufficient protection unless dredging or operation of other equipment could damage the liner. If so, an 18-inch layer of soil is recommended. Sterilization of any underlying organic materials may be necessary, particularly in the case of surface impoundments, to prevent formation of gases and subsequent uplift of the liner. In cold climates, the use of a protective soil cover may be necessary to minimize the possibility of cracking caused by freezing.

(c) Heavy geotextile fabrics (>a 400 g/m2) are increasingly being used in combination with flexible membrane liners in hazardous waste units to protect the membranes from puncture and abrasion. In surface impoundments, geotextiles are also used for gas relief beneath membranes (Collins and Newkirk, 1982). In addition, geotextiles may also serve as a clean base for seaming membrane panels. If geotex-

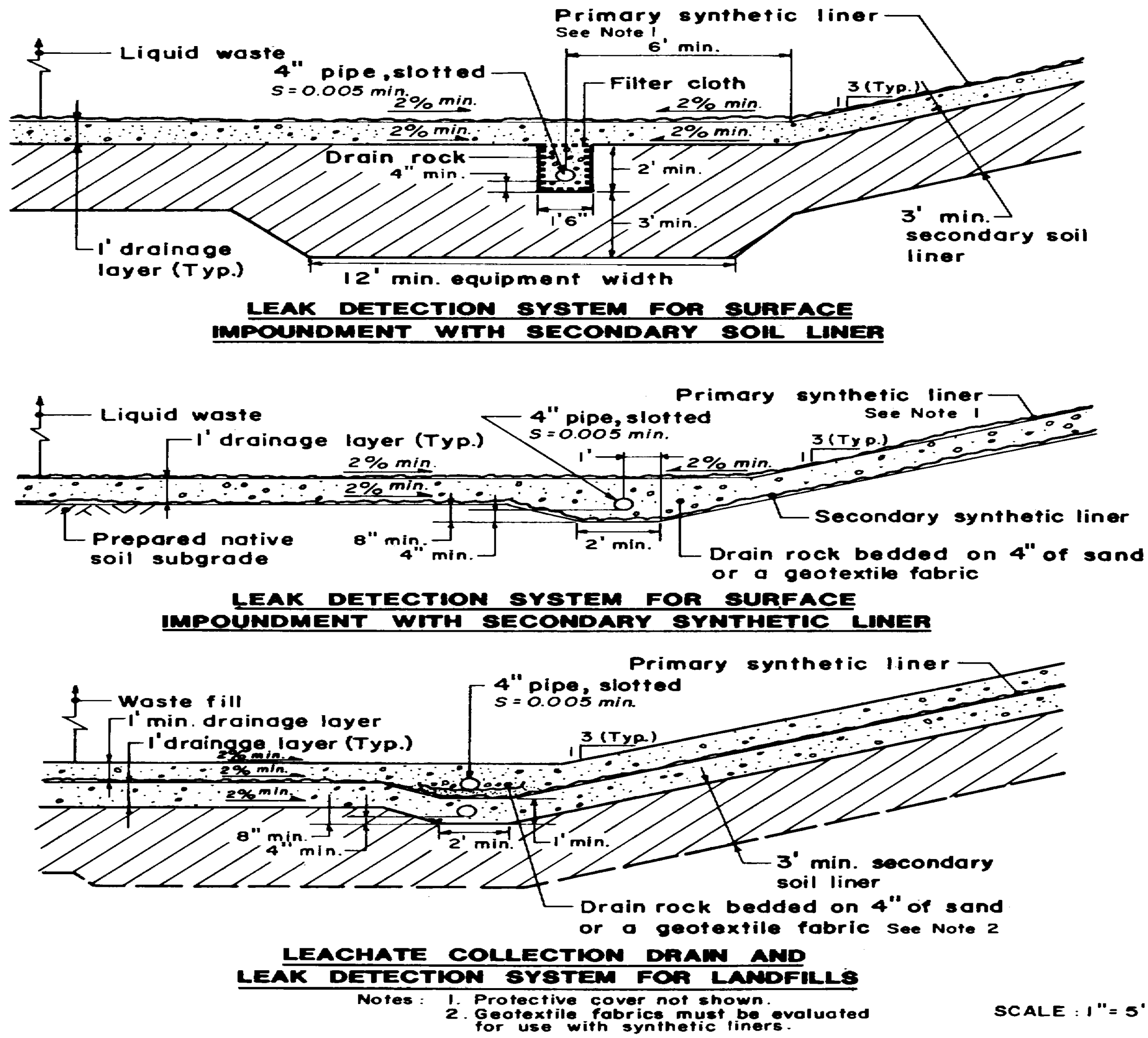


Figure 6-4. Typical clay liner compatibility evaluation.

tiles are used to protect synthetic membranes, it is important that they, like the synthetic membranes, be tested for compatibility with hazardous waste. Only very limited compatibility testing data are currently available on geotextile fabrics; however, many such fabrics are made of polypropylene or polyester materials and may have compatibility characteristics similar to those exhibited by liners of the same materials.

(d) Fabricated liner panels must be constructed so as to minimize the number of field seams and to enable placement of field seams at locations where least severe field conditions occur (e.g., at ridge areas for leak detection and leachate collection systems; see figure 6-2). Project specifications should delineate liner placement procedures for field panel, shop and field seaming procedures, and protective cover requirements. Additional specifications include work responsibilities and quality assurance/certification requirements of the engineer, contractor, manufacturer, fabricator and installer. As part of the project details for the base liner system, a panel installation plan must be prepared with the grading plan.

(e) Aside from puncture and tearing of the liner, the most common cause of liner failure is inadequate seaming. The joining of liner panels should therefore be conducted under controlled conditions, in strict accordance with the manufacturer's recommendations and with installer's trained personnel. The installer should pay strict attention to the overlap specified by the manufacturer, which may range from a minimum of 2 upwards to 12 inches. In addition, field seams shall always be lapped over the downslope liner to prevent piping if a seam fails. Each type of membrane liner also requires specific seaming provisions to achieve an effective bond, as summarized in table 6-3. Since adverse weather conditions (e.g., extreme heat or cold, precipitation, and winds) can affect adequate bonding of the liner field seams, installation should be avoided during these periods.

(f) During placement of the liner and before wastes are placed, tests of the seam strength and bonding effectiveness should be conducted, using visual inspection, air lance, ultrasonic and vacuum techniques. In addition, random samples of seams should be cut from the liner and subjected to on-site and laboratory testing. A replacement patch will be required. Liner placement, seaming and testing are covered in detail in a number of publications, including EPA SW-870.

6-4. Leak detection and leachate collection and removal systems

a. Introduction. The leak detection system, located between the two liners underlying the hazardous waste facility, enables the owner or operator to determine whether any liquid has entered the space between the liners. Should the presence of liquid in this space lead to the discovery that the liner has leaked, the owner/operator will implement procedures to ensure protection of ground water. Leachate collection and removal systems are required immediately above the liners in new hazardous waste landfills and waste piles. Such systems must be capable of maintaining a leachate depth of 1 foot or less above the liner and of withstanding clogging, chemical attack, and forces exerted by wastes, equipment or soil cover. General procedures for designing leachate collection and removal systems are provided in SW-870, paragraph 5-6 and appendix V.

b. Components of the leak detection system. The leak detection system can be a drain system or instrumentation that will permit detection of any liquid that migrates into the space between the liners. Although

Table 6-3. Seaming Provisions for Synthetic Liners'

	Type of compound a	Place used	Solvents	Bodied solvents	Solvent cements	Contact cements	Vulcanizing adhesives	Tapes	Heat sealed	Dielectric
Butyl rubber	XL	Factory	...	...	...	X	X	...	...	...
		Field	...	...	...	X	X	X	...	...
Chlorinated Polyethylene	TP	Factory	X	X	X	X	...	...	X	X
		Field	X	X	X	X	...	X	X	...
Chlorosulfonated polyethylene	TP	Factory	X	X	X	X	...	X	X	X
		Field	X	X	X	X	...	...	X	...
Elasticized polyolefin	TP	Factory	...	...	...	X	...	...	X	...
		Field	..	...	...	X		...	...	X
Ethylene propylene rubber	XL	Factory	...	...	...	X	X	...	...	...
		Field	...	...	...	X	X	X	...	...
Low-density polyethylene	TP	Factory		...		X	...	...	X	...
		Field	...	...	...	X	...	X	X	...
Neoprene (polychloroprene)	XL	Factory	...	...		X	...	..	...	...
		Field	...	...	...	X	...	...	...	...
Poly(vinyl chloride)	TP	Factory	X	X	X	X	...	...	X	X
		Field	X	X	X	X	...	X	X	...

a XL = Crosslinked or vulcanized; TP = Thermoplastic

Adapted from Liner Materials Exposed to Municipal Solid Waste Leachate (Draft), EPA Contract No. 68-03-2134, February 1982 sophisticated instrumentation is available for detection systems, direct collection in a porous medium, with removal through slotted pipes, is a simple and reliable method. Design details for such a system are similar to those for leachate collection and removal systems.

c. Components of the leachate collection system. Specific regulations concerning leachate systems are summarized in table 6-4. EPA guidance documents recommend that the leachate collection system consist of a drainage layer at least 1-foot-thick with a hydraulic conductivity > 1 x 10-3 cm/sec, and a minimum slope of 2 percent. When installed over a secondary clay liner with hydraulic conductivity of 1 x 10-7 cm/sec, such a system provides the four-order-of-magnitude difference in permeability known to significantly increase drainage efficiency.

(1) A drainage layer of clean sand, classified by USCS as SP or SW (with less than 5 percent passing the No. 100 sieve), and free of rock, fractured stone, debris, and cobbles, will also satisfy the EPA requirement for a minimum 6inch protective layer over synthetic liners. A sand layer or filter cloth should be provided over the drainage layer if drainage rock is used to prevent infiltration of fines from the waste and subsequent clogging of the drainage layer. Sands which act as filters must meet filter graduation requirements, such as those shown in chapter 5 of TM 5-820-2.

(2) Nondegradable synthetic filter cloths and geotextile fabrics have also been used to replace granular materials in subdrain systems. However, the long-term performance of such materials has not been firmly established; clogging and filter cake formation can reduce the perpendicular permeability of both geotextiles and filter cloths, and overburden pressures can significantly decrease in-plane permeability of geotextile fabrics.

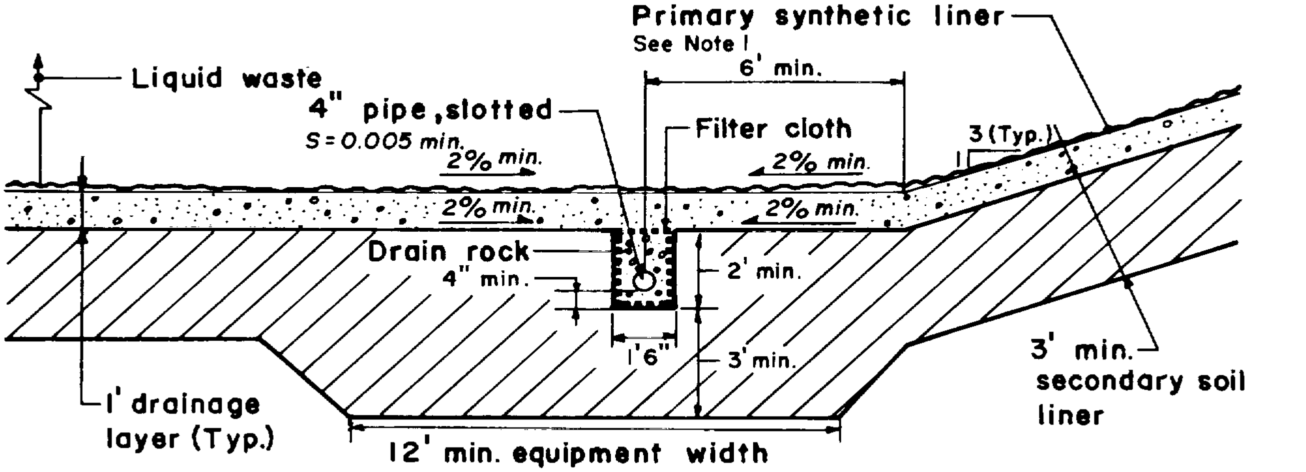
d. Leachate collection pipe. Leachate collection pipe networks should consist of slotted or perforated drain pipe bedded and backfilled with drain rock. The network should include collection pipes, installed around the base of the fill and across the base. Layouts must include base liner slopes >, 2 percent, pipe grades >0.005, and pipe spacing determined for the unit. All pipes should be joined and, where appropriate, bonded.

(1) Collection pipes must be adequately sized and spaced to minimize the leachate head on the liner system. Layouts which incorporate 4-inch-diameter pipes on 50to 200-foot centers are considered adequate by the EPA.

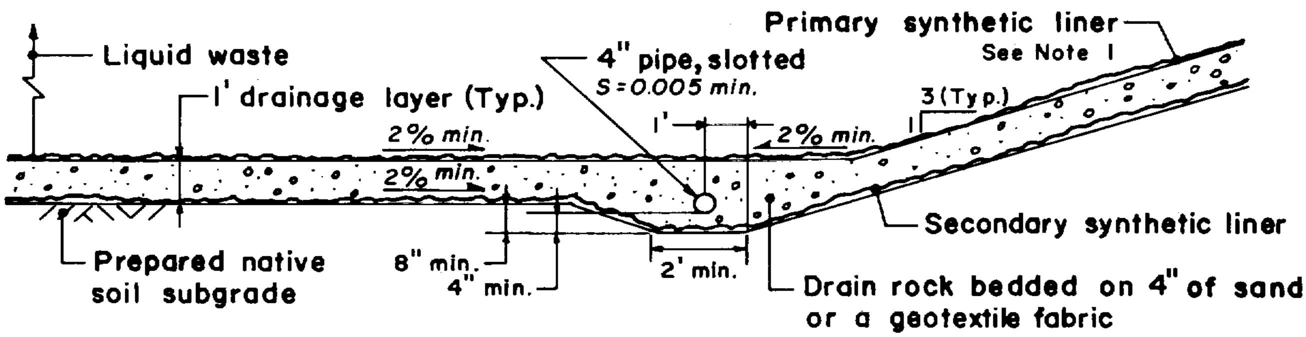
(2) Procedures to evaluate and establish the spacing for collection drain pipes, based upon the anticipated maximum infiltration rate and the hydraulic

Table 6-4. Requirements for Leachate Collection and Removal Systems

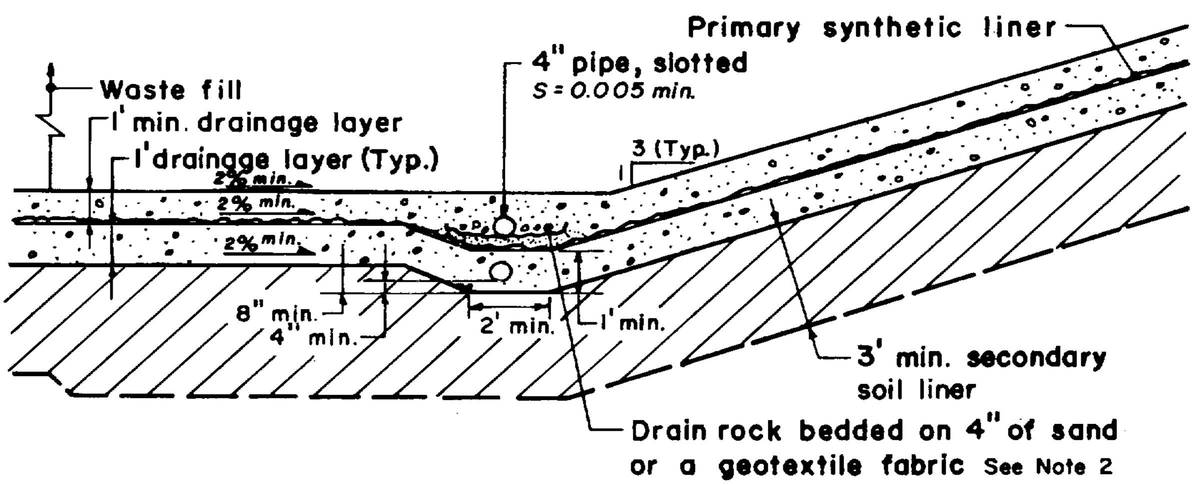
	Section of 40 CFR 264 Describing Requirements			
	K	L	M	N
Design Requirements	Surface Impoundments	Waste Pile	Land Treatment	Landfill
A leachate collection and removal system immediately above the liner that is designed, con- structed, maintained, and operated to collect and remove leachate from the unit The Regional Administrator will specify design and operating conditions in the permit to ensure that the leachate depth over the liner does not exceed 30 cm (one foot) The leachate collection and removal system must be constructed of materials that are:				
Chemically resistant to the waste managed in the unit and the leachate expected to be generated; and Of sufficient strength and thickness to prevent collapse under the pressures exerted by overlying wastes, waste cover materials, and by any equipment used at the unit; and Designed and operated to function without clogging through the scheduled closure of the unit	NA	264.251(aX2)	NA	264.301(aX2)
While in operation, leachate collection systems should be inspected weekly and after storms for the presence of leachate and proper functioning of the systems	NA	264.254(bX4)	NA	264.303(bX4)
After closure, continue to operate the no longer detected Adapted from 40 CFR 264	NA	NA	NA	264.310(bX3)



LEAK DETECTION SYSTEM FOR SURFACE IMPOUNDMENT WITH SECONDARY SOIL LINER



LEAK DETECTION SYSTEM FOR SURFACE IMPOUNDMENT WITH SECONDARY SYNTHETIC LINER



LEACHATE COLLECTION DRAIN AND LEAK DETECTION SYSTEM FOR LANDFILLS

Notes: 1. Protective cover not shown.
2. Geotextile fabrics must be evaluated for use with synthetic liners.

SCALE: 1" = 5'

Figure 6-5. Typical leak detection systems and leachate collection drains conductivity of the drainage layer material available, are presented in EPA SW-873, EPA SW-870 and EPA 625/1-81-013.

e. Leak detection and leachate collection drains. As shown in figure 6-5, trench installations can be used for leak detection drains in secondary clay liners. Projecting installations should be used for synthetic liners. Slopes for bedding should be no steeper than the angle of repose of the drainage layers and all slope breaks should be rounded. Collection drains over synthetic liners should incorporate a 4-inch-minimum bedding of clean sand (SP) to satisfy requirements for liner protection. Drain rock used over synthetic liners should be rounded pea gravel. Geotextile fabrics might be evaluated to serve as an alternative protective measure.

f. Leachate collection sump and riser. The current state-of-the-art in leachate collection system design uses sumps or basins at low points on the base of the fill to which the leachate collection network discharges. A riser pipe extending from the sump to the ground surface enables leachate removal. The lower segment of the riser pipe in the drain rock of the sump is slotted, and can be connected to a slotted header pipe in the sump to allow a higher rate of flow to, and withdrawal from, the riser pipe.

(1) The riser must be of a diameter that will accommodate a pump suction line or submersible pump. The riser pipe can be installed in a trench excavated in the wall of the clay liner, or bedded in suitable soil on the surface of the synthetic liner.

(2) Leachate collection networks for landfills, which must remain functional during the 30-year postclosure period, should include pipe cleanouts extending from major collection drains to the ground surface, to enable system inspection and/or cleaning.

g. Design considerations. In designing a leachate collection system, one must consider resistance to chemical attack, prevention of clogging, and pipe stability.

(1) All components of leachate collection systems must be able to withstand the chemical attack which can result from waste or leachate. Plastic (PVC and polyethylene) and fiberglass piping are usually selected for such systems; however, if solvents in the waste stream contain organics capable of attacking collection pipes, sumps or risers, an alternative to the use of plastic or fiberglass piping might be concrete or cast iron. Any geotextile filter cloth or fabric used in the leachate collection system shall be evaluated for its ability to withstand attack from the hazardous waste and the leachate generated from that waste.

(2) The drainage layer, any geotextile filter cloth or fabric, drain rock, pipe slotting, and waste fines must be evaluated to determine the ability of the system to transmit leachate without clogging. Although the EPA guidance document recommends use of a granular layer above the drainage layer, if clean sand is used for the drainage layer, it will serve to preclude plugging and possibly eliminate the need for a filter cloth or fabric.

(3) The pipe used in leak detection and leachate collection systems must be of sufficient strength and thickness to withstand the pressures exerted by the weight of the overlying waste, the cover materials, and any equipment to be used on the waste unit. Slotting will reduce the effective strength of pipe and its ability to carry loads and resist pipe deflection under loading. The capacity of buried pipe to support vertical stresses may be limited by buckling and by the circumferential compressive strength of the pipe. Information on deflection, buckling capacity and compressive strength may be obtained from the pipe manufacturer.

(a) Even when correctly designed to withstand waste loading, piping can fail from equipment loading during construction or operation of the waste unit. Moving loads result in impact loading one and one-half to two times greater than stationary loading. Therefore, equipment should, if possible, not cross leachate collection drains installed in projecting installations or in trenches with shallow cover. When equipment must be routed across a drain, impact loading should be minimized by mounding material over the pipe to an adequate depth to prevent pipe failures.

(b) Specific design procedures and examples used to determine loads resulting from the waste fill and/or construction equipment are provided in appendix V.2 of SW-870.

6-5. Surface water run-on and run-off control systems

a. Regulatory requirements. Surface water run-on and run-off control systems are required for landfills, waste piles and land treatment units and indirectly for surface impoundments. Regulatory requirements for surface water control at land disposal facilities are summarized in table 6-5. While federal regulations require control systems for 24-hour, 25-year storms, state regulations may require sized control for storms with a return frequency up to 100 years. In such cases, the more stringent requirement should be considered in sizing surface water run-on and run-off control facilities. The designer must also size collection and holding facilities, and develop specific management procedures to enable all run off from active disposal areas to be retained for treatment prior to its evaporation or discharge to natural drainage courses or back to an approved hazardous waste facility.

b. Types of control systems. Run-on and run-off control systems at hazardous waste units utilize a variety of structures for control of surface water, including conveyance, barrier and control/retention systems.

Table 6-5. Requirements for Surface Water Run-on and Run-off Control Systems

	Section of 40 CFR 264 Describing Requirements			
	K	L	M	N
Design Requirements	Surface Impoundments	Waste Pile	Land Treatment	Landfill
Design, construct, operate and maintain a run-on control system capable of preventing flow onto the active portion of the treatment zone during peak discharge from at least a 25-year storm.	NA	264.251(c) a	264.273(c) b	264.301(c) a
Design, construct, operate and maintain a run- off management system to collect and control (at a minimum) the water volume resulting from a 24-hour, 25-year storm	NA	264.251(d) C	264.273(d)C	264.301(d)
Design, construct, maintain and operate to prevent overtopping or overfilling by wind and wave action, rainfall and run-on	264.221(c)	NA	NA	NA
Collection and holding facilities for run-off control systems must be emptied or otherwise managed after storms to maintain design capacity of the system.	NA	264.251(e)	264.273(e)	264.301(e)
While in operation, inspect weekly and after storms to detect evidence of deterioration, malfunctions, or improper operation of run-on and run-off control systems	264.226(b)(1)d	264.254(bX1)	264.273(c)	264.303(bX1
After closure, maintain the run-on control system and the run-off management system.	NA, unless closed as a landfill	NA, unless closed as a landfill	264.280(3),(4) 264.280(cX3),(4)	264.310(bX5)d

a The active portion.
b The treatment zone.
c Does not state that this pertains to the active portion; however, it is assumed to be such.
d This subsection of 40 CFR 264 indirectly applies.
Adapted from 40 CFR 264

(1) Typical examples of conveyance facilities, as well as erosion control measures, are provided in EPA 600/2-79-165, section 10. Examples of standard surface water control facilities, along with design procedures for their selection, design and construction, are provided in the Engineering Field Manual for Conservation Practices published by the US Department of Agriculture, Soil Conservation Service (SCS). Examples of conveyance facilities used for run-on and runoff control at hazardous waste units are shown in figures 6-6 through 6-8 and described below. These figures show grass areas with slopes of 2:1; note, however, that any vegetated final slope areas to be tractor mowed should have slopes no greater than 3:1.

2) Examples of barrier conveyance and detention/retention systems include:

Barriers:	berms, dikes
Conveyance:	swales, ditches, channels, pipe cross drains and over- side drains with inlet and outlet appurtenances; pipedrop inlets, hooded inlets, drop and chute spillway structures
Detention/retention:	sedimentation control basins and run-off retention basins

c. Run-on control systems. Drainage berms, ditches and overside drains or spillways can be selected and designed to prevent flow onto the active portion of waste units during peak discharges from specified return storms. Drainage swales and ditches with berms can be located to intercept and convey water run-on flows around hazardous waste sites and around waste units within the site. To reduce the potential for erosion and minimize maintenance, spillways or overside drain systems should be considered for steep ditch reaches and where collected flows must be carried down slopes for discharge.

(1) If there is any chance that overflows could damage constructed elements of waste units or enter active operation areas, they should be sized for carrying peak flows from storms with return frequencies upwards to 100 years. Erosion control measures for the conveyance system should be evaluated and selected to minimize maintenance over the anticipated service life. As described in paragraph 6-5d(2), conveyance systems developed for the waste unit perimeter to intercept run on may also be used to intercept run off from closed areas, if the surface water does not require retention.

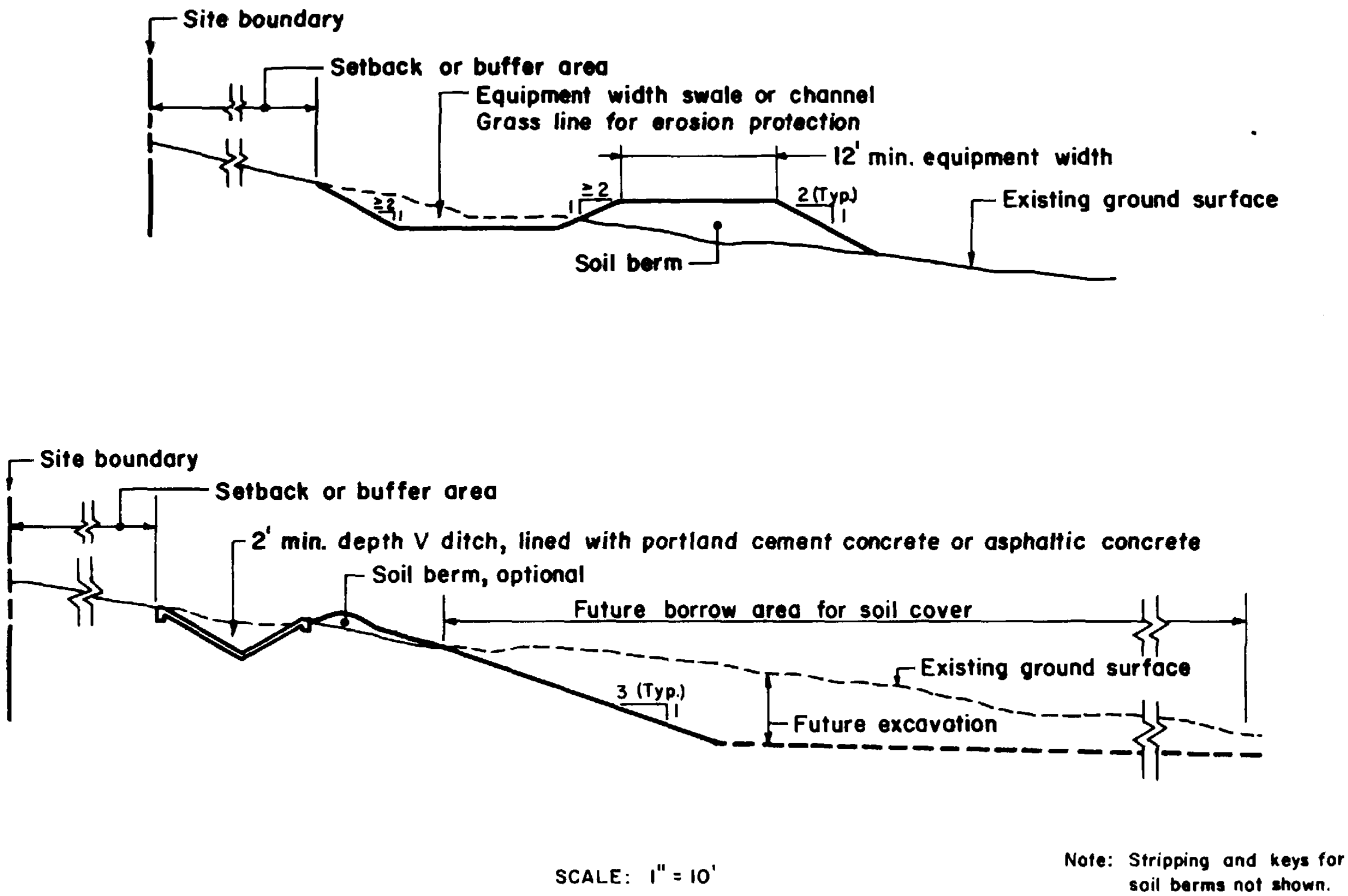


Figure 6-6. Typical run-on control ditches.

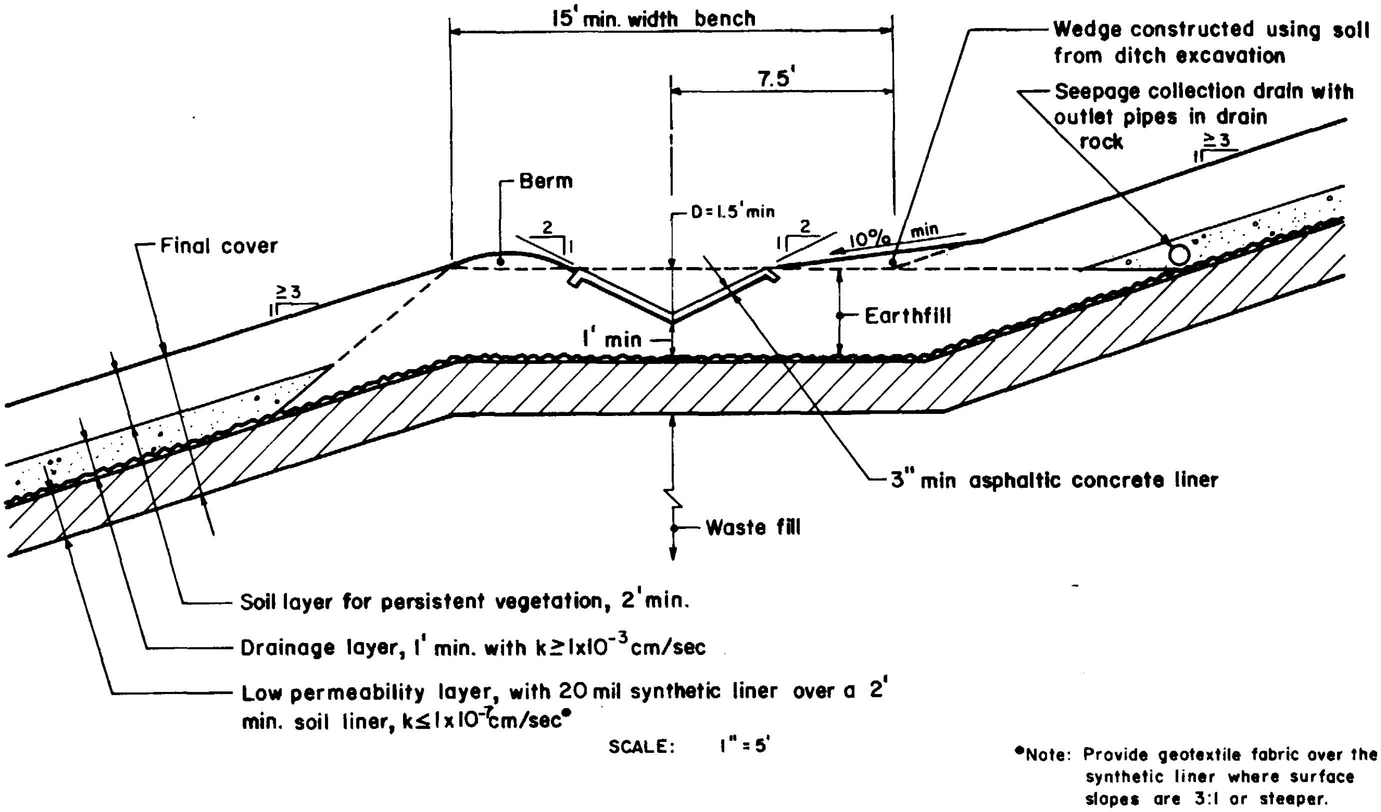
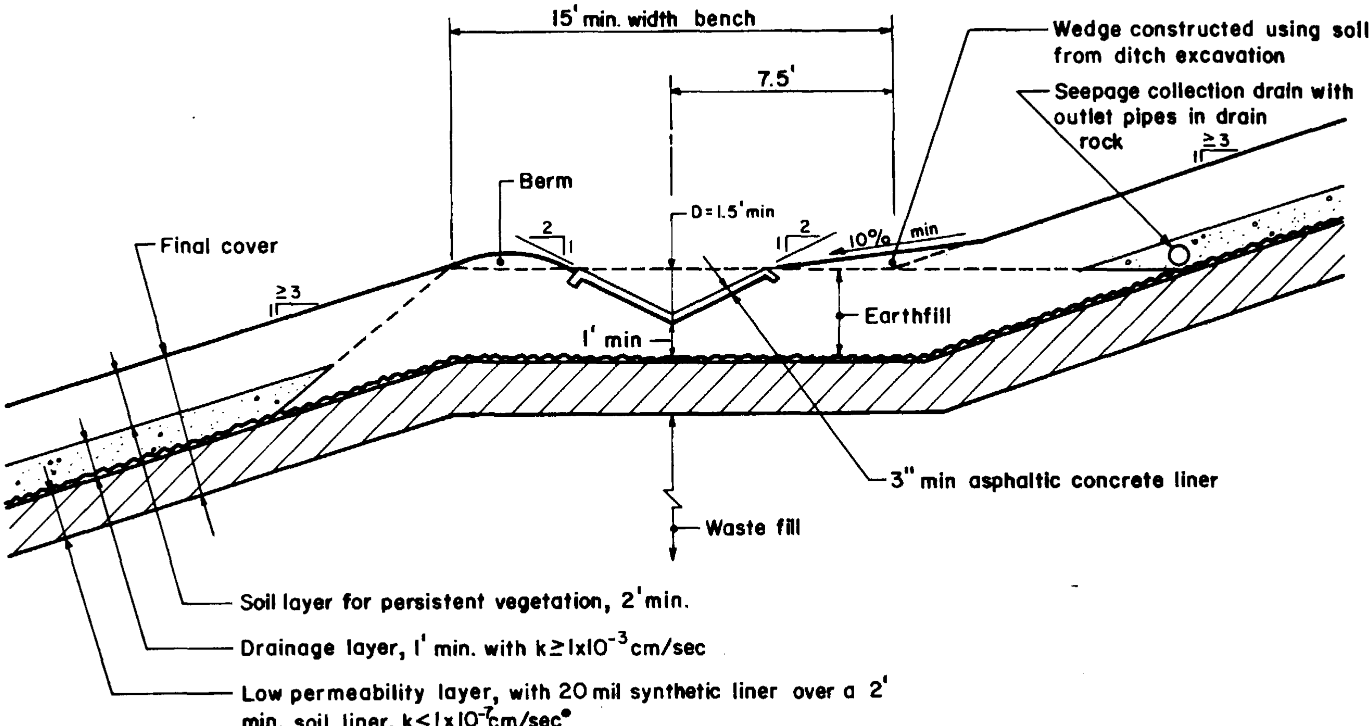


Figure 6-7. Typical run-on control ditch for waste units.



SCALE: 1" = 5'

*Note: Provide geotextile fabric over the synthetic liner where surface slopes are 3:1 or steeper.

Figure 6-8. Typical run-off control ditch for final cover areas.

(2) Sedimentation controls should be established for onsite borrow areas and construction areas. Where possible, facilities for control of sediment transport should be located near the source, so that only sediment-laden waters need be handled. The near-source system requires less extensive structures than the downstream sedimentation control basin alternative for intercepted run-on flows.

(3) Sediment control facilities for source areas include:

(a) Temporary Sediment Basins-At construction areas, where run off is usually confined to ditches or depressions in the topography, basins can be constructed by excavating shallow depressions and placing berms or sandbags to contain water for sedimentation.

(b) Silt Barriers-Where sheet flow occurs (on perimeter construction slopes, and in large excavations), silt fences or hay bales placed in a shallow trench can be positioned to intercept run off and remove sediment. Silt fences normally consist of filter cloth fastened to wire fencing.

(c) Vegetation-Completed borrow areas, inactive stockpile areas, and final cover areas can be seeded, fertilized or hydroseeded to establish a vegetative cover which will provide erosion and sediment control. When vegetation has become established, downgradient silt fences or other sedimentation control structures may be removed.

(4) Sedimentation control basins (figure 6-9), used for settling out sediment being carried by surface flows, are often established at discharge locations by constructing containment dikes and excavating a basin area. To discharge surface water, emergency overflow spillways and pipe drains are typically provided.

(5) The principal maintenance requirement for sedimentation basins is removal of accumulated sediment by draglines or loaders during dry-weather periods.

d. Run-off control systems. Run-off control systems which handle surface water flows from active portions of hazardous waste units and any site staging areas that might contain wastes residue must include collection and holding facilities (figure 6-9). These facilities retain run off for treatment before its release, evaporation, or discharge back to an approved hazardous waste facility.

(1) For large sites located in semi-arid regions, collection and holding facilities might be developed to receive run off from the majority of the site, rather than specific waste units. Such facilities could easily be sized to retain and effect evaporation of run-off volumes much larger than those from the required 24hour, 25-year storm, ensuring full containment while minimizing operational requirements. For sites located in more humid areas, the immediate waste handling areas and active disposal units should be confined, and operations effectively controlled, to enable collection and retention of the minimum volume of run off which may best be treated for release, or discharged back to an approved hazardous waste facility.

(2) The conveyance systems developed to carry run off from active areas of waste units, and the retention facilities developed to contain run off, must prevent any release of liquid. Closed pipes or ditches with synthetic liners should be considered for waste piles and landfills.

(3) Conveyance systems within land treatment units may include unlined terraces and grass waterways for both application of liquid waste, and for intercepting flows and minimizing erosion within the land treatment area.

(4) Retention facilities designed for all waste units should meet either storage or surface impoundment requirements. However, a lower area of either waste unit might be developed and used for the retention and treatment of run off from active areas. The adequacy of the retention basin size should be demonstrated, based upon a monthly tabulation of run-off storage requirements, and the methods for emptying the basins and dispersing of the accumulated waters, (i.e., treatment and discharge, evaporation, spray irrigation, solidification, etc.).

(5) Procedures which may be required to minimize the active area from which run off must be collected could include internal berms, synthetic cover, encapsulated wastes, and restrictions during wet-weather periods.

e. Sizing run-on/run-off control systems. Methods used to predict run-off volumes and peak flow rates include the Rational Formula, empirical expressions and charts of the USDA's Soil Conservation Service (SCS), and various hydrographic procedures. Both the Rational Formula and the SCS charts provide predictions which can be used in sizing surface water control systems at disposal facilities.

(eq 6-1)

(1) For the Rational Equation: $Q = CiA$

where: Q = flow rate (cfs)

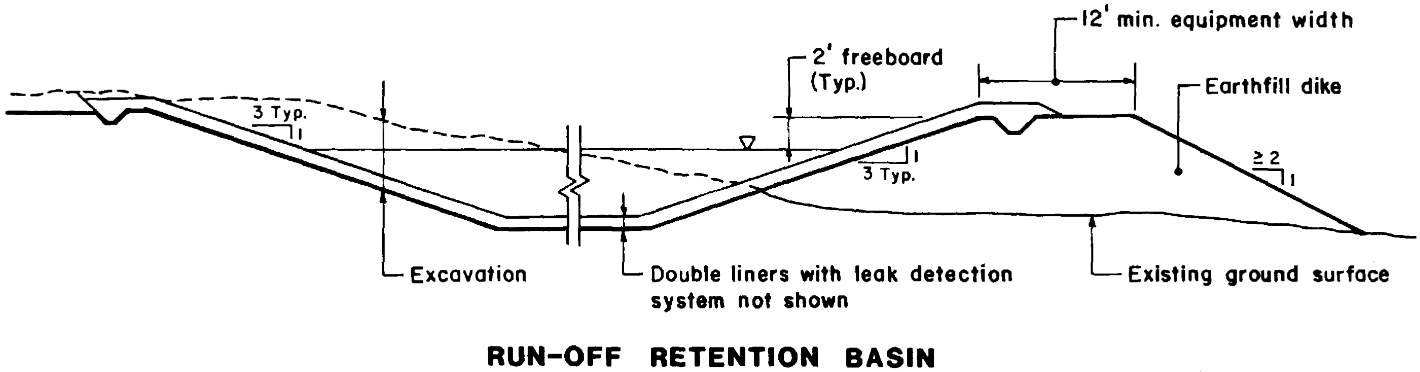
C = run-off coefficient (assumed)

i = intensity of rainfall (inches/hour) for the selected design duration and frequency

A = tributary area, in acres

(2) The value of C for sizing run-off control systems should be 0.8 to 1.0 when the active areas are barren or lined. The same factor should also be used to determine the volume of run off into holding facilities over the specified period of time. Run-off coefficients for other surface conditions applicable to land disposal facilities are available in TM 5-820-4.

(3) The SCS method provides empirically based



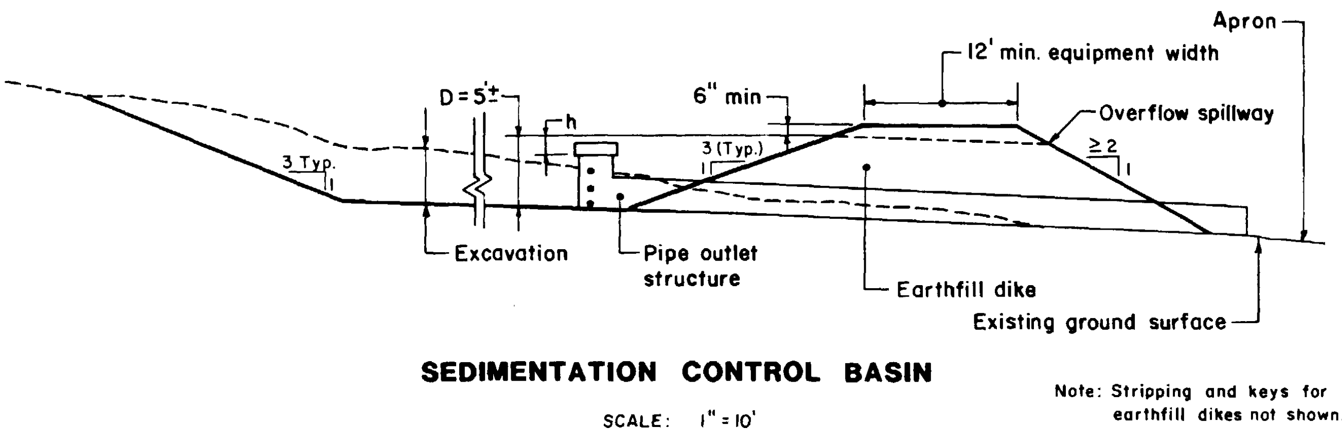


Figure 6-9. Run-on sedimentation control/run-off retention basins.

charts for determining the peak rate of discharge from small watersheds, based on values for surface soil types and antecedent moisture conditions. Basic information and values are summarized in EPA 60012-79-165 and detailed in the US Department of Agriculture's engineering field manual.

(4) Sedimentation basins are sized based on analysis of settlement time for suspended solids, i.e., sands, silts and clays. Sizing procedures are provided in TM 5-820-1 through TM 5-820-4. The trapping efficiency of a basin is related to its surface area; the basin's depth only provides for sediment storage. The latter document provides an assessment of SCS sizing criteria, and demonstrates that constructing basins to control clay-sized particles during peak flows may not be practicable because the basins would need to be ten times larger that those used for control of silts.

6-6. Gas control systems

a. Introduction. Gaseous emissions from hazardous waste land disposal facilities-including landfills, surface impoundments, and land treatment sites-generally fall into two categories: (1) methane gas, produced by the anaerobic decomposition of organic wastes, and (2) toxic vapors, produced by the volatilization of chemical wastes. Methane gas, explosive in concentrations of 5 to 15 percent by volume in air, is generated mainly in landfills containing organic wastes; waste volatilization can occur at landfills, surface impoundments and land treatment sites.

(1) There are no specific regulations for control of gaseous emissions at hazardous waste facilities. In landfills containing organic wastes, compliance with the RCRA solid waste criterion for explosive gases is recommended (40 CFR section 257.3-8). This criterion stipulates that methane concentrations at the property boundary not exceed the lower explosive limit (LEL) of 5 percent; in facility structures the limit is 25 percent of the LEL, or 1.25 percent methane.

(2) EPA regulations do not specifically address the effects of hazardous waste land disposal facilities on air quality, due to the limited information on emissions from such facilities and the fact that the problem is waste-specific. However, 40 CFR 241.206-2 recommends that the need for gas control should be assessed; if the need for control measures is warranted, the location and design elements for vents, barriers or related systems should be provided on design plans for the facility. A collection system is not required at new facilities if the owner/operator can demonstrate that no gas will be produced or, if produced, would neither contribute any air pollutant to the atmosphere nor create a flammable or explosive environment.

b. Control techniques. Control techniques for volatile emissions from surface impoundments and land treatment sites are largely preventive in nature. Emissions from surface impoundments can be minimized by increasing impoundment depth and decreasing surface area, and by constructing wind barriers. Removal of volatiles from the waste stream by stream stripping, distillation or incineration can also be used, where practical. In all cases, codisposal of reactive and/or incompatible wastes should be avoided. At land treatment facilities, volatilization can be mitigated by injecting volatile substances at least 6 inches below the ground surface into moist but friable soils.

(1) Venting is required at surface impoundments if gases accumulate beneath a liner and build up pressure. Sufficient gas pressure can lift the liner, creating an area where additional gas can accumulate. The higher the "gas bubble" rises, the more the membrane stretches and the less the hydrostatic pressure is able to restrain the membrane. If this condition is not controlled by venting, the liner could rupture or float to the surface of the impoundment.

(2) A number of control alternatives are available at landfills. Choice of the appropriate control system will depend on control objectives and involve determination of the type of wastes present, the depth of fill, and the subsurface characteristics of the sites and adjacent areas. In addition, field measurements should be used to determine gas concentrations, positive and negative pressure, and soil permeability.

(3) Atmospheric pipe vents, either of the "U" or mushroom configuration, can be used in landfills to control vertical movement of gases; they are most effective in areas where gases are collecting and causing pressure buildup. For example, venting is effective in preventing uplift of the top liner following closure of a landfill. Forced ventilation, on the other hand, provides an effective means of controlling both lateral and vertical migration of gases. Such systems usually employ a series of pipe vents or wells installed within lined landfills and are connected by a manifold to a motor blower. The effectiveness of vent trenches can be increased by capping the trench with clay or other impervious material and employing lateral and riser pipes connected by a manifold to a motor blower. The gas to be vented or withdrawn from the landfill may require collection and treatment to control odors and to prevent discharge of volatile toxics to the atmosphere.

c. Design considerations and constraints. Pipe vents are usually constructed of perforated PVC pipe installed in a gravel pack to prevent clogging and encourage gas migration to the vent. They should be sealed to prevent excess air from entering the system and to prevent methane or volatile toxics from leaking out. The key design considerations in installation of pipe vents, as part of either atmosphere or forced ventilation systems, are proper placement and spacing. An additional consideration for forced ventilation systems is the gas flow rate. Flow rates should be at least equal to the rate of gas production but low enough to prevent excess oxygen from being drawn into the system. Details concerning proper design of pipe vent systems are contained in Methane Generation and Recovery from Landfills, EMCON Associates (1980).

(1) Vent trenches are constructed by excavating a deep trench which is backfilled with gravel to provide a path of least resistance through which gases can migrate vertically. Design considerations in constructing vent trenches include ensuring proper ventilation by backfilling with sufficiently permeable material and avoiding infiltration of precipitation and clogging by solids. In passive closed vent trenches, ventilation can be enhanced by proper design of laterals and risers.

(2) In active vent trenches with forced ventilation, the equations and design criteria for active control wells apply, with allowances for the smaller area and greater permeability of the trench backfill. The key design consideration for vent trenches is that the depth of the trench extend to the ground-water table or an unfractured impervious stratum to prevent gas from migrating under the trench.

6-7. Final cover

a. Regulatory requirements. Final cover is required for closure of all hazardous waste landfills, surface impoundments developed for waste disposal, and those surface impoundments and waste piles at which all contaminated subsoils cannot be removed or decontaminated at closure.

(1) Specific regulations concerning final cover are summarized in table 6-6. The prime function of finmal cover is to minimize infiltration of precipitation. Other functions include preventing contamination of surface water run off, wind dispersion of hazardous waste, and direct contact with hazardous waste by animals or humans. To prevent liquid accumulation within closed disposal units, the regulations specify final cover must have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

(2) For long-term performance with minimum maintenance, the final cover must be designed to promote drainage, minimize erosion, preclude accumulation of gas pressures, and accommodate settling and subsidence.

b. Elements of the cover system. Design features and criteria recommended for final cover in the EPA guidance documents are shown in figure 6-10. The recommended three-layered final cover includes:

* A soil layer for vegetation
* A drainage layer
* A low permeability layer

(1) The upper soil layer is to sustain vegetation and minimize erosion of the cover; the middle drainage layer is to carry infiltrating water from sustained precipitation to the sides of the cover for discharge; the low-permeability layer is to prevent fluid inflow and ensure that infiltrating water is carried by the drainage layer.

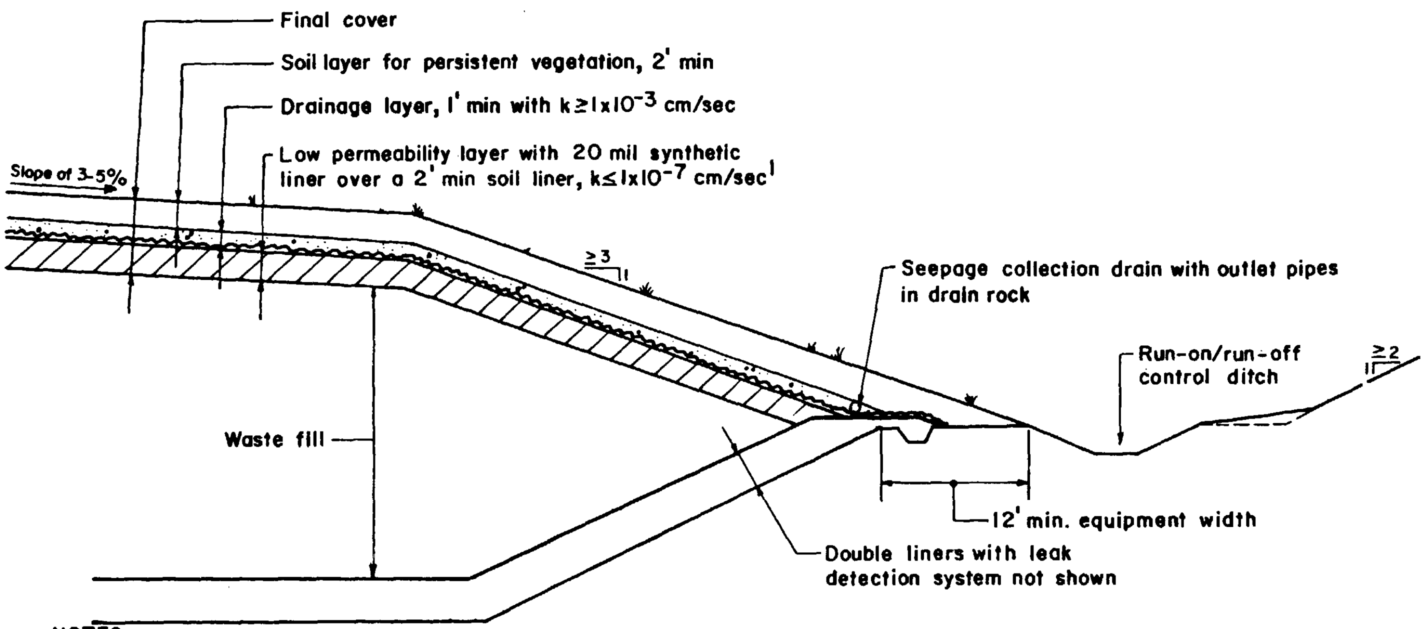
(2) An overview of procedures for evaluating clo-

Table 6-6. Requirements for Surface Water Run-on and Run-off Control Systems

	Section of 40 CFR 264 Describing Requirements			
	K	L	M	N
Design Requirements	Surface Impoundments	Waste Pile	Land Treatment	Landfill
Cover the unit with a final cover designed and constructed to: ' Provide long-term minimization of the migration of liquids through the closed unit. Function with minimum maintenance Promote drainage and minimize erosion or abrasion of the final cover Accommodate settling and subsidence so that the cover's integrity is maintained; and Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.	264.2282(iii)	May apply	NA	264.310(a)
Maintain the integrity and effectiveness of the final cover, including making repairs to the cap as necessary to correct the effects of settling, subsidence, erosion, or other events.	264.228(bXl)	May apply*	NA	264.310(bXl)
Prevent run-on and run-off from eroding or otherwise damaging the final cover.	264.228(bX4)	May apply'	NA	264.310(bX5)

*If not all contaminated subsoils can be practicably removed or decontaminated, the unit must be closed in accordance with requirements that apply to landfills.

Adapted from 40 CFR 264



NOTES:
1. Provide geotextile fabric over the synthetic liner where surface slopes are 3:1 or steeper
2. Provide run-off control ditches for final cover areas where needed to minimize surface erosion

SCALE: 1" = 10'

U.S. Army Corps of Engineers

Figure 6-10. Final cover details.

sure covers is provided in EPA SW-867. More detailed design criteria and procedures are provided in EPA 600/2-79-165 and EPA SW-873.

(3) The low permeability layer includes a minimum 2-foot-thick soil liner and a synthetic membrane at least 20 mil thick. General design, selection, and construction procedures for both synthetic and clay liners are provided in paragraph 6-2.

(a) soils suitable for the lower liner are native clay materials, or soils blended with clay, bentonite, or other additives, which can exhibit, when placed on a firm base, a recompacted permeability of 41 x 10-7 cm/sec. The soil liner should generally fall into the CL/CH Unified Soil Classification System, with not less than 50 percent by weight passing a No. 200 sieve (U.S. Standard), a liquid limit between 35 and 60, and a plasticity index above the "A" Line in the plasticity chart of the USCS. Any additive which increases the soil's vulnerability to cracking by settlement or excessive shrinkage should be avoided.

(b) Achievable field densities for cover soil liners are generally less than for base liners, because waste fill areas provide a softer, more flexible construction subgrade. The designer should obtain laboratory tests of the permeability of representative soil liner samples remolded to achievable field densities at moisture contents greater than optimum to establish construction procedures for low in-place permeability of the soil liner.

(c) The designer should specify moisture conditioning requirements, the thickness of soil layers for compaction, the type and weight of equipment, and the number of equipment passes required to achieve the required density/permeability and avoid flexural cracking during placement. The constructed soil liner shall be protected from drying until placement of the synthetic membrane. Spraying with water or application of an emulsion to prevent drying may be necessary.

(d) The EPA guidance documents specify a synthetic liner at least 20 mil thick; demonstration of the liner's compatibility with the waste or leachate is not required in this case, because the liner is not expected to be in contact with waste or leachate. Nevertheless, liner selection should be based upon its resistance to the waste present and to degradation, as well as its ability to undergo deflection due to settlement without cracking or tearing.

(e) The synthetic liner must be protected both above and below by a layer of material no coarser than sand. Sands should be classified as either SW or SP by the USCS, with less than 5 percent passing the No. 100 sieve. In addition, sands which act as filters must meet filter graduation requirements, such as those shown in chapter 5 of TM 5-820-2. The synthetic liner can be placed directly on the soil liner with adequate protection, provided the upper 6 inches is no coarser than sand and free of rock, fractured stone, debris, cobbles, rubbish, and roots. A drainage layer selected to meet the requirement for bedding material can be used above the liner.

(f) Where surface slopes are 3:1 or steeper, geotextile fabrics are recommended for placement over the synthetic liner. Heavy geotextile fabrics >, 12 oz/yd are increasingly being used in combination with flexible membrane liners in hazardous waste units to protect the membranes from puncture and abrasion. If geotextiles are used to protect synthetic membranes, it is important that they, like the synthetic membranes, be tested for compatibility with hazardous waste. However, many such fabrics are made of polypropylene or polyester materials and may have compatibility characteristics similar to those exhibited by liners of the same materials.

(g) Care must be taken to avoid any penetration of the liner. Where inlets or outlets are required (e.g., for an impoundment), inflow/outflow piping should be designed to go over the top whenever possible. Energy dissipaters may be needed at the pipe inlet/outlets. Where penetrations cannot be avoided, precautions must be taken to ensure an adequate seal between the liner and any unavoidable penetration. In such cases, flange-type connections should be considered. EPA SW-870 outlines procedures for sealing between the liner and any penetration.

(h) EPA requires that the liner must also be protected from damage by sudden changes in slope; to prevent liners from freezing, they must be located entirely below the frost line. Procedures are provided in EPA 600/2-79-165.

(4) The drainage layer must be at least 12 inches thick, exhibit a permeability of >1 x 10-3 cm/sec, and be able to carry infiltrating waters to the sides of the cover for discharge.

(a) The designer should carefully evaluate the drainage layer for its ability to carry waters for discharge, and the need for a synthetic fabric filter or graded granular layer to prevent plugging due to infiltration of soils from the vegetated soil cover layer. Measures should be considered to preclude piping of the drainage layer at discharge areas.

(b) Selection of a clean sand (SP), which exhibits the required permeability and is able to carry the volume of infiltrating water, will not only satisfy the bedding requirements for the synthetic liner, but may also eliminate the need for a granular layer to prevent plugging; nevertheless, a synthetic fabric filter should be considered to ensure the long-term effectiveness of the drainage layer.

(c) Although the EPA guidance documents indicate drainage collection devices are not necessary, a perforated drainage collection pipe to intercept and carry water from the drainage layer to surface drainage facilities may be a better alternative than granular drainage discharge areas.

(5) The soil layer for vegetation should be a high quality topsoil at least 2 feet thick, and capable of sustaining vegetation.

(a) The vegetation must be a persistent but shallow-rooted species which will minimize erosion, while not penetrating below the vegetative and drainage layers (EPA SW-867 and EPA 600/2-79-165). The vegetated soil layer must also have an erosion rate of < 2.0 tons per acre per year using the US Department of Agriculture Universal Soil Loss Equation (USLE). This equation and data for its use are described in EPA SW-867 and EPA 600/2-79-165.

(b) As noted, steeper perimeter slopes must be provided with surface drainage systems capable of conducting run off across the slope without damaging the vegetated soil cover. Stability against slippage under saturated or seismic conditions must also be demonstrated.

c. Design considerations. Because hazardous waste fills can undergo settlement, and any damaging effect of settlement on final cover must be repaired during the post-closure period, the designer should assess the potential for uniform settlement of the waste fill, recommend operating practices which minimize differential settlement, and select construction slopes which minimize the damaging effect of settlement.

(1) Settlement of waste fills generally occur due to

(a) Mechanical consolidation: a decrease in void space related to applied load(s) of the fill and soil cover and their depth.

(b) Biological decomposition: a decrease in volume by loss of solids.

(c) Displacements: differential settlements which result from liquefaction of saturated layers, creep of the waste fill, and/or collapse of drums placed prior to the ban of such practice.

(2) In new facilities, where design procedures minimize foundation settlement, and placement procedures minimize differential settlement of the fill, consolidation of the waste fill will be the primary source of settlement. The potential for settlement should be analyzed for the following conditions: compression of the foundation and compression of the waste due to dewatering, liquefaction, primary and secondary consolidation, biological oxidation of organics, * and chemical conversion of solids to liquids. EPA SW-873 provides current state-of the-art design information to determine settlement, and additional studies are being performed for EPA.

(3) The following provisions should be considered to minimize damage by anticipated settlement:

(a) Selecting design slopes which will minimize the damaging effect of settlement, i.e., use 4 percent construction slopes for upper surfaces over fill areas where settlements can be expected to be uniform, due to placement procedures and a uniform depth of fill, and use 10 to 33.3 percent slopes (10:1 to 3:1 horizontal to vertical slopes) over perimeter and interim fill areas, where the depth of fill increases significantly due to the perimeter excavation, and can result in settlements which decrease the construction slope by 10 percent or more (see figure 6-10).

(b) Using uniform fill placement and solidification procedures which minimize differential settlement and enable prediction measurements for the order of settlement that can be expected after closure.

(c) Staging final closure to delay placement of final cover where substantial settlement is expected (may require an extension in the 180-day limit for closure, and placement of an expendable interim cover).

(4) Design slopes should be selected to allow for any settlement. Final slopes should be at least 3 percent to prevent ponding due to irregular surface areas, but less than 5 percent to prevent excessive erosion. Perimeter slopes may be steeper, but must be provided with surface drainage systems capable of conducting run off across the slope without forming erosion rills and gullies. Steeper slopes must be evaluated for stability against slippage under saturated or seismic conditions, and for acceptable resistance to erosion.

6-8. Special design elements

a. Regulatory requirements. Regulations within sections of 40 CFR 264 establish design, construction and maintenance requirements for structural integrity of impoundment dikes, overtopping controls, and wind dispersal controls. Requirements related to air emissions have not been established, but are expected to be developed in the future by EPA. The specific regulations are summarized in table 6-7.

b. Design considerations for dikes. Since dikes are the principal containment components of surface impoundments and are partially or completely above ground, it is essential that they be designed, constructed and maintained with sufficient structural integrity to prevent failure. Dike slopes must be stable at all times, especially during rapid drawdown of waste liquids; they must also be protected against erosion due to wave action, wind, rain or animal intrusion. Dikes must be designed so that excessive stresses are not put on the foundation.

(1) To accomplish these goals, the designers must evaluate the materials of construction, liner type(s), weather factors, loads imposed by wastes, drainage systems, and the hydrologic and geotechnical characteristics of the site. Analyzing the stability of the pro-

* Calculate assuming one pound of organic matter will be destroyed for each two pounds of oxygen consumed in a BOD5 test.

Table 6- 7. Requirements for Special Design Elements

Design Requirements	Section of 40 CFR 264 Describing Requirements K Surface Impoundments	L Waste Pile	M Land Treatment	N Landfill
Dikes				
Dikes are designed, constructed, and maintained with sufficient structural integrity to prevent massive failure of the dikes. In ensuring structural integrity, it must not be presumed that the liner system will function without leakage during the active life of the unit.	264.221(d)	NA	NA	NA
Weekly inspection for severe erosion or other signs of deterioration in dikes.	264.226(bX4)	NA	NA	NA*
Overtopping				
The unit must be designed, constructed, maintained, and operated to prevent overtopping resulting from normal or abnormal operations overfilling; wind and wave action; rainfall; run- on; malfunctions of level controllers, alarms and other equipment; and human error.	264.221(c)	NA	NA	NA
Weekly inspections to detect evidence of deterioration, malfunctions, or improper operation of overtopping control systems.	264.226(bXl)	NA	NA	NA
Wind Dispersal				
If the unit contains any particulate matter which may be subject to wind dispersal, the owner or operator must cover or otherwise manage the unit to control wind dispersal.	NA	264.250(cX3)	264.233(f)	264.301(f)
Inspected weekly and after storms for proper functioning of wind dispersal l control systems,) where present.	NA	264.254(bX3	264.273(gX2)) 264.280(aX5)	264.303(X)(3

* No standards or requirements established.
Adapted from 40 CPFR 264

posed or existing dike system is of primary importance; slope failure due to saturation, earthquake or poor construction could result in extensive environmental, property and human damage.

(2) Stability assessments should utilize in situ properties of the dikes and foundations and pertinent geologic information. Assessment methods and evaluative criteria are presented in NAVFAC DM 7.1 and EPA SW-873. Evaluations and monitoring must be repetitive to ensure structural integrity and containment of liquids.

c. Prevention of overtopping. Surface impoundments must be designed, constructed, maintained and operated to prevent overtopping. Designing impoundments with significant freeboard, establishing operating practices to monitor and regulate liquid levels, using automatic liquid level controllers, and/or using alarms can prevent overtopping.

(1) Specific guidance requirements to preventing overtopping include:

* For stormwater: design and operating provisions which can withstand, at a minimum, the flow generated by a 24-hour, 100-year storm.

*For flow-through units: adequately sized spillway or weir-type discharge structures which can maintain a constant liquid level and freeboard.

-pipes with valved intakes and outlets for regulating flows.

-pumping systems for control of inflows and outflows.

· For units without outlets: provisions to assess the freeboard level and regulate inflow to prevent overtopping.

(2) A 2-foot freeboard is documented as providing sufficient protection against overtopping due to inflow fluctuations or wave action; however, when manual operation is involved, greater freeboards may be necessary to ensure protection.

(3) Water balance studies must be performed for evaporation surface impoundments. The summation of liquid wastes volume and precipitation inflows, minus the evaporation losses, determines the anticipated liquid levels. The EPA believes stormwater should be diverted from surface impoundments. The guidelines to accomplish this are that structures be designed to di-

vert the maximum flow from a 100-year storm, unless the volume of the contributing flow will not cause appreciable loss of freeboard.

(4) If overtopping is imminent or a failure occurs, provisions must be available to divert flow to another unit or stop the inflow.

d. Control of wind dispersal. Wind dispersal control measures are required for waste piles, land treatment areas, and landfills. The generation and dispersion of dust from a hazardous waste unit can pose potential health hazards as well as affect visibility. Dust emissions can occur by wind erosion of exposed soil or waste areas, vehicle traffic on unpaved haul roads, and soil handling activities.

(1) Although watering for immediate control can be an effective short-term wind dispersal method, additional control methods should be implemented to minimize long-term wind erosion of open soil or waste areas. Control methods include physical, chemical or vegetative stabilization of exposed surfaces.

(2) Physical stabilization involves covering exposed surfaces with a material that prevents wind from disturbing the surface particles; materials used for this purpose include rock, soil (including daily and intermediate cover), crushed or granulated clay, bark or wood chips. Chemical stabilizers, often used in conjunction with water, can provide dust suppression for several months. Since many of these chemical compounds are proprietary, their characteristics are difficult to evaluate without site-specific field testing. Information concerning these chemical stabilizers, including a discussion of their characteristics, is presented in EPA 600/2-79-165.

(3) A more permanent solution .to controlling wind dispersal of dust is vegetating exposed inactive soil borrow areas, land application areas, and soil stockpile areas. Vegetative cover not only serves as a permanent method of suppressing dust, it also serves to enhance the aesthetics of the site. The particular vegetative species selected should be compatible with soil type, growing conditions, climate, and site end use. Additional information concerning selection of vegetative species and planting techniques is presented in EPA 600/2-79-128.

(4) Control provisions to reduce or eliminate the generation of fugitive dust from unpaved haul roads include (1) physical stabilization (placing a gravel layer on the road), or (2) chemical stabilization (application of binding materials).

(5) Imposing speed reductions on unpaved roads during dry weather can also help to reduce dust generation.

(6) For land treatment facilities, wind dispersal control measures include (1) surface wetting (irrigation) with water or chemical agents, (2) development of a vegetative cover, (3) windbreaks, and (4) waste application timing. The specific control measure(s) selected will depend on site-specific conditions. Additional information concerning wind dispersal control for land treatment units is available in EPA SW-874 and the EPA Office of Solid Waste Draft RCRA Guidance Document for Land Treatment.